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Power Quality Improvement in QUCEST Larkana Campus by using Three Types of Power Filters

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ABSTRACT

The increase of power electronic converters at the end-user side is unavoidable and it will cause current harmonic distortion and wide range of disturbance in the power system (PS). This paper presents current harmonic compensation for the test case of the Quaid-e-Awam University College of Engineering Sciences and Technology (QUCEST) Larkana campus in MATLAB SIMULINK by using three types of power filters i.e. passive, active and hybrid power filters. The purpose of this experiment and simulation model is to analyse and find out the best solution for reducing the current harmonic and unbalanced load condition at the incoming transformer to the campus. Moreover, this paper presents the testing and comparison of the active and hybrid power filters by using the combined design technique of harmonic compensate control system based on Unit Vector Template (UVT) and Instantaneous Reactive Power (IRP) theory. The simulation results allow to identify the effectiveness of the control system along with passive filter. Based on the testing and simulation results of three types of power filters, hybrid power filter has the maximum ability to mitigate the current harmonic in the system, and it also reduces the neutral current thus causing less stress in the existing system.

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1. INTRODUCTION

Practically three situations of the utility and consumer are found. One is sinusoidal supply connected to the linear load. Another is sinusoidal supply connected to the non-linear load. The third one is non-sinusoidal supply connected to the non-linear load which is worst most than the first two. The growing utilisation of electronic gadgets in power distribution system origin the quality of the power making it ruined. The core idea of the electric utility is to transfer sinusoidal voltage at literally stable magnitude throughout the system. This aim is complex by the fact that there are loads in the system that generate harmonic currents. These harmonic outcomes in distorted voltages and currents can harmfully crash the system performance in dissimilar ways [1], [2].

Conventional electrical power distribution system was designed for linear loads, therefore it is less concern to deal with harmonics. However, with the rise of changeable speed drives like adjustable speed drives and the electronic devices that need to be adjusted, will drag and draw the current and thus by causes no more synchronised with the voltage waveform. This nature of non-linear load will cause various order harmonic currents that are being injected into the power distribution system [3], [4]. The increase of non-

linear loads is unavoidable, but the constantly increase demand of the non-linear loads at the end-users side had caused the harmonic beyond the standard limit [5]. The increasing result of the current harmonic may cause breakdown of sensitive electronic equipment, failure of protective devices and overheating in transformer windings [6], [7]. The IEEE Standard 519 and IEC 61000-3-2 state the permissible total harmonic distortion (THD) of voltage and current with limits being as 8 % and 5 % respectively [8-10].

Harmonic in PS can be mitigated by using power filters like passive power filter (PPF), active power filter (APF) and hybrid active power filter (HAPF). PPF is the first type of filter that is installed to compensate current harmonics. The PPF provides the advantages of simple and cost effective. However, the PPF is designed to compensate certain order of harmonics, which is not suitable for variable loads. Since the appeal of power electronic (PE) devices in the PS, PPF became less effective due to the PE devices generating more complex harmonics [11], therefore APF is designed to overcome the drawback of PPF [12]. Although, APF provides good harmonic compensation but the cost is expensive because it requires a high value of the DC-link capacitor. Therefore, HAPF combination of PPF and APF is designed, which consists both advantages of PPF and APF. HAPF can compensate wide range of harmonics with the cost cheaper than APF but higher than PPF [13], [14].

This paper shows the experimental evaluation of PQ issues at QUCEST campus by using power quality analyser (PQA). A simulation analysis of a three-phase system of QUCEST will be carried out by using MATLAB/SIMULINK based on the observations. Measurements were conducted by using PQA at the point of common coupling (PCC) of transformer secondary terminals, connecting to load. According to the collected data by PQA, it shows that the PS is facing high current harmonics and unbalanced load condition due to the non-linear loads connected. The simulation model of QUCEST campus functions to provide the similar waveforms and harmonic spectrum of each phase of the transformer. This simulation model will use as the testing model for power filter in order to find out the best current harmonics solution for QUCEST campus.

2. CASE STUDY – QUCEST CAMPUS

QUCEST is fed by two power supplies, which are Sukkur Electric Power Company (SEPCO) and diesel generators (standby). Both these supplies are coupled with automated transfer switch (ATS) with 400 kVA transformer and power is drawn from 600A circuit breaker, connecting to the whole campus as shown in Figure 1. The testing is made at the secondary of the transformer panel with PQA. Harmonic voltages and currents are the integral multiples of the fundamental frequency (50 Hz in Pakistan).

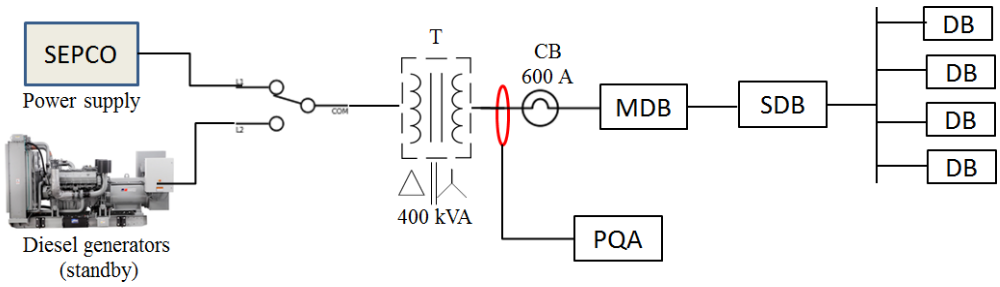

Figure 1. Block Diagram of the Testing System

Table 1 depicts the tested results of three-phase (RYB) incoming of the transformer. From the collected data, it shows that the transformer is in an unbalanced condition. For an ideal condition, three phases of the transformer loading had to be same, but for practical, the variation between each phase must not exceed 10 % [15]. This unbalanced load condition might be the effect of the connected non-linear loads such as computers, air conditioners controls etc. because non-linear behaviour will cause power losses in the PS. An unbalance load to three phases of the transformer results a high line current in one or two phases. The high current in two phases can limit the transformer capacity, which means a transformer rated 1000 kVA may deliver only 750 kVA or less. Therefore, the unbalanced load at transformer may cause transformer losses and heating in its winding [16].

Voltage and current waveforms of RYB phases are shown in Figure 2. The THD of voltage (THD_V) of each phase is less than the standard value stated by IEEE-519 ($THD_V \leq 8$ %). Therefore, the voltage waveforms are not distorted and not harmful to the PS. The current THD (THD_I) on RYB phases are 8.9 %, 17.5 % and 10.1 %, respectively, which is greater than the standard value so the current waveforms are completely distorted and harmful when connected to the PS.

Table 1. Transformer incoming RYB phases tested results with PQA

Phase	Red (R)	Yellow (Y)	Blue (B)
Vrms (V)	234.7	231.1	236.3
% THD_V	0.8	1.2	0.8
Irms (A)	170.2	136.8	104.0
% THD_I	8.9	17.5	10.1
Active power (kW)	38.7	31	23.4
Reactive power (kVAR)	8.4	8.2	6.4
Apparent power (kVA)	39.6	32	24.2

Figure 3 shows the MATLAB simulation model of QUCEST campus and Table 2 is the load parameters of the simulation model. The simulation model parameters are set according to the actual test case. Parameters of the real system were obtained by using PQA. The loads are fed by the three-phase power supply from a delta-star transformer. The simulation model main purpose is to get a similar result of the tested result as shown in Table 3.

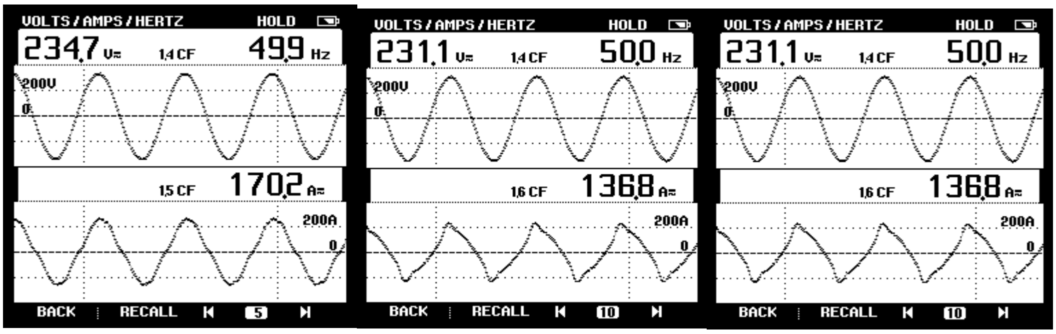

Figure 2. Voltage and current waveform for RYB phases

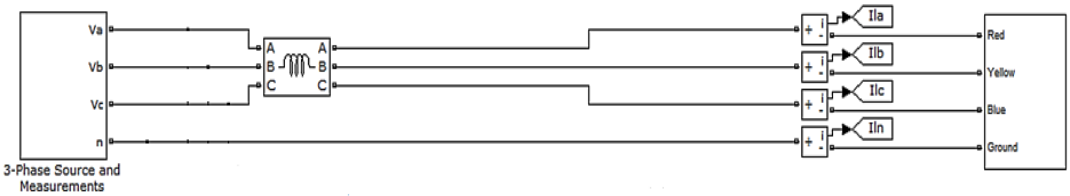

Figure 3. MATLAB simulation model of QUCEST campus

Table 2. Load parameters of MATLAB simulation model

Phase	Red (R)	Yellow (Y)	Blue (B)
Source voltage, Vrms (V)	235	230	236
$L_{line-impedance}$, mH	0.01	0.04	0.11
L_{load}, mH	1.4	2.7	2.88
R_{load}, Ω	1.31	1.52	2.15

From Table 3, it can be seen that the current magnitude of each phase, THD_I, active and reactive power values of the simulation results are close to the tested results. It also shows that the three-phases had an unbalanced load. Therefore it verifies that the MATLAB model is valid and can be used as the system model to design any type of filter. Figure 4 shows the load and neutral current of the simulation model. Due to the non-linear loads connected in the system, it causes an unbalanced load connected to the transformer,

causing an increase in neutral line current i.e. up to 51.47 A_{rms}. Based on the IEEE-519 standard, the neutral line current must be less than the nominal working current. Although, high neutral line current is not contributed to THD_I, but it will cause the heating of the neutral cable and winding equipment like motor and transformer thus reducing the equipment service life and increase the power loss in the system. Moreover, if the imbalance is huge, the circuit breaker will trip or fuse will rupture/blow off. Therefore, the neutral line current is recommended as low as possible in order to avoid the side effects as mention before.

Table 3. Comparison between tested and simulated results of QUCEST campus model

Phase	Red (R)		Yellow (Y)		Blue (B)	
	Tested	Simulated	Tested	Simulated	Tested	Simulated
Irms (A)	167.4	170.8	136.8	135.5	108.9	99.9
% THD_I	8.9	8.85	17.5	17.5	10.1	10.09
Active power (kW)	38.7	39.12	31.0	30.97	23.4	23.43
Reactive power (kVAR)	8.4	8.36	8.2	8.28	6.4	6.27
Apparent power (kVA)	39.6	40.0	32.0	32.06	24.2	24.25

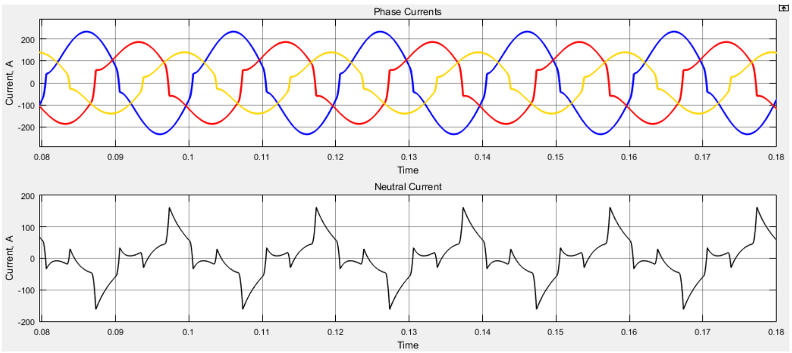

Figure 4. Simulation mode source and neutral current waveforms

3. POWER FILTER DESIGN

The unbalanced current flow in the line is caused by harmonic generated by the connected nonlinear loads in the system. In order to improve the system performance and reduce the harmonics, various types of power filters are used as detailed below:

3.1. Passive power filter (PPF) Sub section 1

PPF is made up of passive components such as resistors (R), inductors (L), and capacitors (C). In this paper, the single tuned filter is used. Single-tuned filters possess series RLC connected in parallel with the non-linear load. It is the most common type of PPF used in PS. The single-tuned filter design is based on the optimum filter design [8], [17], where the RLC component parameters can be determined by adopting following procedures:

a. Determine the capacitor size. For this case, the required reactive power (Q_c) is about 30 kVAR. Hence the capacitive reactance (X_c) and the capacitance (C_x) for the filter is calculated by:

$$X_C = \frac{V^2}{Q_C} \quad (1)$$

$$C_X = \frac{1}{\omega X_C n} \quad (2)$$

Where,
V = the rms value of phase voltage (240 V);
ω = 2πf;
n = number of a filter to be design

b. The inductance value (L_x) for the filters is calculated by:

$$L_X = \frac{1}{(\omega h)^2 X_C} \tag{3}$$

Where,
h = harmonic order

c. The resistance (R) value of the filter is calculated by:

$$R = \frac{\sqrt{L_X / C_X}}{Q} \tag{2}$$

Where,
Q = Quality factor.

The Q is used to determine the sharpness of tuning, which can categorise the high Q or low Q types [18]. Mostly, for the Q value of $30<Q\leq100$ is used for tuned lower harmonic frequency. However, for a wide of tuned frequency, the Q value is $0.5<Q\leq5$. In this case, the selected Q value is 1, which is selected on the basis of optimum filter design [17]. Table 4 shows the design parameter of the PPF. Figure 5 shows the simulation model of QUCEST campus with 5th, 7th and 9th order single-tuned filter.

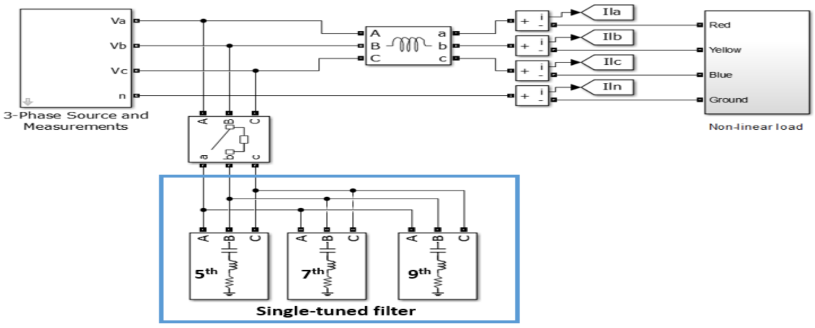

Figure 5. The simulation model of QUCEST campus with three single-tuned filters

Table 4. The PPF parameters

	Physical value		
Harmonic order	5th	7th	9th
C_X, mF	1.658	0.829	0.553
L_X, mH	0.244	0.249	0226
R, Ω	0.384	0.548	0.639

3.2. Active power filter (APF)

APF as the alternative to the PPF for recent years is adopted due to the development of the power electronic devices. The APF can be categorised into two topologies which are series APF (used for voltage harmonic compensation) and shunt APF (used for current harmonic compensation). The APF function is to introduce current or voltage components with opposite magnitude of the harmonics to cancel out the harmonic components of the nonlinear loads. However, the system of an APF is much complicated, which includes coupling inductor ($L_{coupling}$), control system, and voltage source inverter (VSI) with a DC-link capacitor (C_{DC}). Altogether its function is to inject opposite harmonic current/voltage to reduce harmonic distortion. Table 5 shows the design parameters of the shunt APF used in this paper. Figure 6 shows the simulation model of QUCEST campus with shunt APF. The control method and the design parameters of the shunt APF are presented in [19].

Table 5. The shunt APF parameters

Parameter	Physical value
DC-bus voltage, V_{DC}	700
$L_{coupling}$, mH	1
C_{DC}, μF	2000

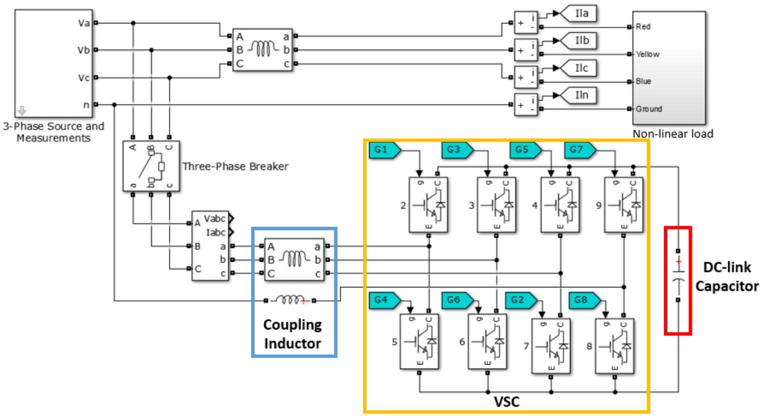

Figure 6. The simulation model of QUCEST campus shunt APF

3.3. Hybrid Active Power Filter (HAPF)

HAPF is the combination of PPF and APF possessing both advantageous characteristics. However, HAPF can be implemented in PS in two kinds of condition. First, for nowadays normally for big building or industry PS already equipped with PPF or APF to improve the system harmonics. In case, the user had intended to upgrade the existing PS into HAPF can do by install either a parallel PPF to a shunt APF or vice versa. As the results, the user able to improve the system power quality without interference with the existing built-in system [20], [21]. Figure 7 shows the simulation model of QUCEST campus with HAPF, that is a combination of a 7th single-tuned filter with the physical value as in Table 4 and shunt APF with the same design parameter and control theory as in Table 5.

The second condition is the HAPF that install to a system that not included any types of the power filter. Figure 8 shows the simulation model of QUCEST campus with HAPF. The PPF used is the 5th single-tuned filter with the physical values depicted in Table 4. For the APF side, the control method is IRP theory like the shunt APF. However, for this kind of HAPF given advantages of reducing the V_{DC} and C_{DC} values to 400 V and 1000 μF respectively. This is due to the 5th single-tuned filter will function to tune out dominant frequency in the system and supplying the required reactive power for power factor correction. However, the APF portion is dedicated to removing other harmonic orders [22], [23].

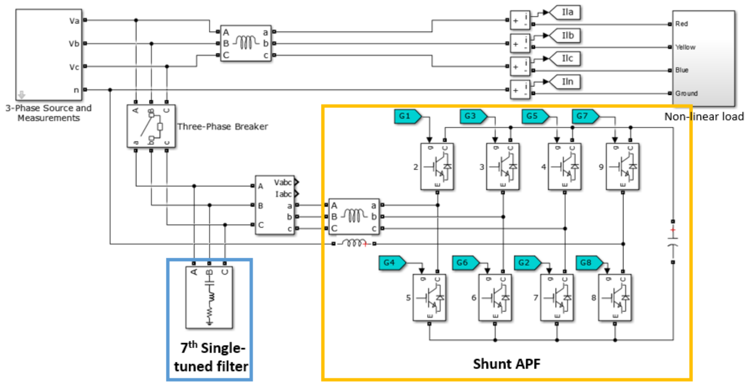

Figure 7. The simulation model of QUCEST campus with the combination of 7th single-tuned and shunt APF types of HAPF

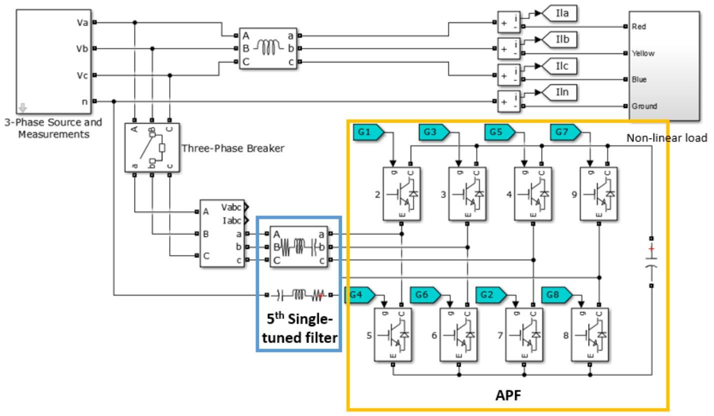

Figure 8. The simulation model of QUCEST campus with HAPF

4. SIMULATION VERIFICATION

In this section, the simulation results of the simulation model of QUCEST campus under harmonics compensation in five cases as shown in Table 7. During the simulation, the power filters are switching ON in time 0.1 s. Based on the depicted results of five simulated test cases in Table 7. Table 8 shows the summary of the effect of five simulated cases for QUCEST campus.

In the Case 2, the simulation results of the RYB phases and neutral current waveforms are shown in Figure 9 and the corresponding Table 8. The RYB phases current still remain unbalance and the phase current increases to more than 300 % before compensation. The increase in nominal current is due to the impedance of the single-tuned filter, which means that by adding filter in the system it will increase the system impedance resultant higher system current. This condition will cause overloading to the cable and tripping of the protective devices. Moreover, it is also observed that the PPF is not able to reduce the neutral current harmonic. Moreover, the PPF will be ineffective if the current rating of the system increase.

Table 7. Simulation results of five cases for QUCEST campus

Phase		Red (R)		Yellow (Y)		Blue (B)	
Case	Method	I_{rms} (A)	THD_I (%)	I_{rms} (A)	THD_I (%)	I_{rms} (A)	THD_I (%)
1	No filter	170.8	8.85	135.5	17.5	99.9	10.09
2	PPF	533.1	3.92	501.9	6.48	471.2	3.03
3	Shunt APF	189.4	3.01	184.8	2.54	188.6	3.12
4	7^{th} PPF + Shunt APF	269	2.12	264.3	2.12	261.4	2.24
5	HAPF	196	1.94	191.6	2.65	195.3	1.62

Table 8. Summary of the effect of five cases for QUCEST campus.

		Phase current, I_{rms}				
Case	% THD_I of R, Y, B phases IEEE 519 (≤5%)	Balanced/ Unbalanced	% increase to nominal current	% rise while switching ON	Cause of % rise in phase current	Neutral current, A
1	RYB > standard	Unbalanced	-	-	-	51.47
2	Y > standard	Unbalanced	>300	600	C_x, L_x, R of 5^{th}, 7^{th}, 9^{th} PPF	51.45
3	RYB < standard	Balanced	>10	30	$L_{coupling}$	0.49
4	RYB < standard	Balanced	>40	250	C_x, L_x, R of 7^{th} PPF and $L_{coupling}$	0.99
5	RYB < standard	Balanced	>15	100	C_x, L_x, R of 5^{th} PPF	5.65

In the Case 3, the simulation results of the RYB phases and neutral current waveforms are shown in Figure 10 and the corresponding Table 8. The RYB phases THD_I are reduced and satisfy the standard

permissible values and the RYB phases current remain balanced. Moreover, the neutral current amplitude is also reduced. It proves that the unbalance condition is caused by the connected non-linear loads not by improper design of the three-phase loading.

In the Case 4, the simulation results of the RYB phases and neutral current waveforms are shown in Figure 11 and the corresponding Table 8. Figure 12 shows the harmonic compensate current at the PCC. The RYB phases THD_I are reduced and satisfy the standard permissible values and the RYB phases current remain balanced. However, the phase current increases to more than 40 % compared to before compensation, due to the impedance of the 7^{th} single-tuned filter. Besides that, it also observed that the designed filter able to reduce the neutral current harmonic. Although, the Case 4 given a better results than Case 2 and Case 3, but the increases of RYB phase current and high values of switching on impulse may beyond the designed protective devices and the cable carrying capacity.

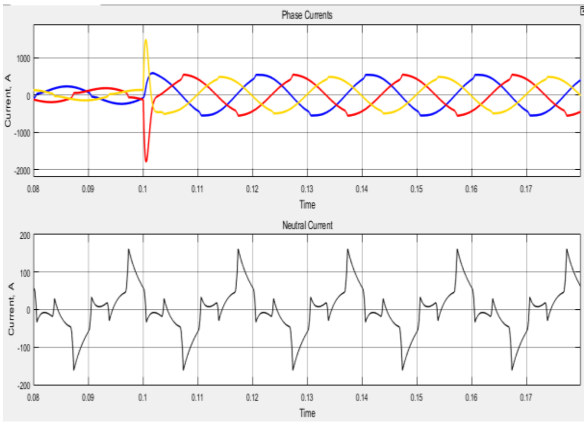

Figure 9. Source and neutral current waveforms for Case 2

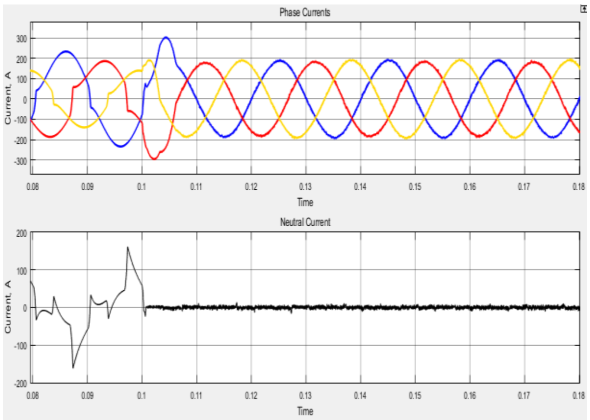

Figure 10. Source and neutral current waveforms for Case 3

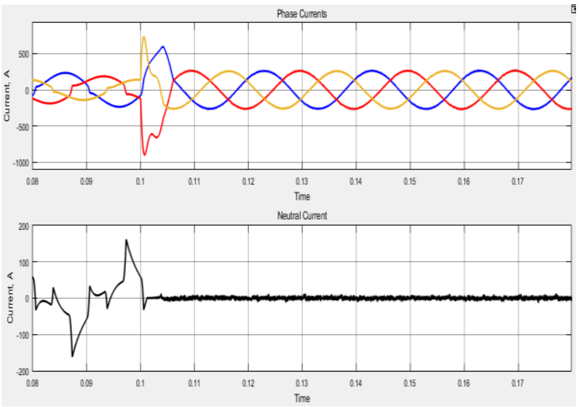

Figure 11. Source and neutral current waveforms for Case 4

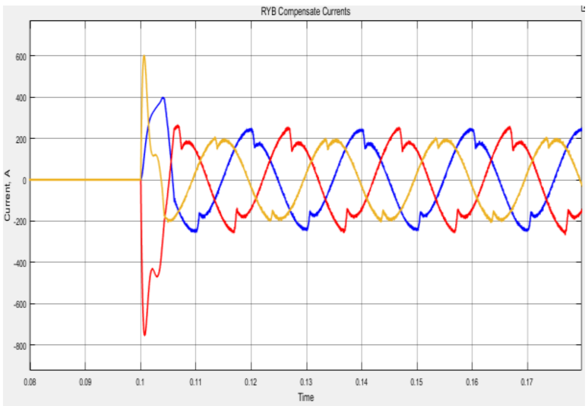

Figure 12. 7^{th} PPF harmonic compensate current waveforms for Case 4

In the Case 5, the simulation results of the RYB phases and neutral current waveforms are shown in Figure 13 and the corresponding Table 8. Figure 14 shows the harmonic compensate current at the PCC. The RYB phases THD_I are reduced and given the best results among other cases and the RYB phases current remain balanced with low values of neutral current. Only the RYB phase current is slightly more than Case 3. This condition is due to the impedance of the 5^{th} single-tuned filter that connected in series with the APF.

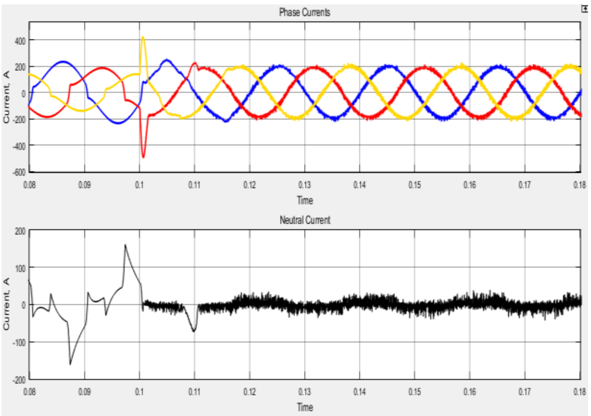

Figure 13. Source and neutral current waveforms for Case 5

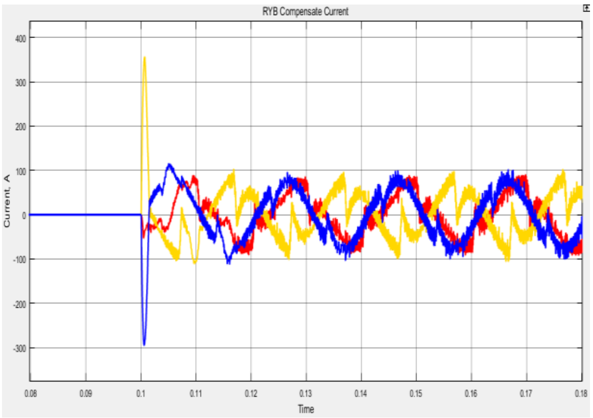

Figure 14. Harmonic compensate current waveforms for Case 5

Table 9 shows the suitability of the case to be installed for the QUCEST campus and reasons.

Table 9. Suitability and the reason of the case for the QUCEST campus.

Case No.	Suitable to be installed for the QUCEST campus?	Reason
1	-	-
2	No	a. Expected future expansion in load. The PPF will be ineffective if the current rating of the system increase and unpredicted unbalanced load caused by harmonics.
3	Yes	b. Given good harmonics compensation with minimum rise of phase current in nominal condition and switching period.
4	No	c. The increases of RYB phase current may beyond the designed protective devices and the cable carrying capacity. This may cause uncertain tripping and heating in the cable.
5	Yes	d. Gives the best harmonics compensation compared to other methods without causing a burden for the existing built-in system.

5. CONCLUSION

The loading of a three-phase transformer model of the QUCEST Larkana campus was analyzed for harmonics through MATLAB/Simulink. Then it was tested by using PQA. The waveforms and the line spectrums so far obtained from the simulation and observed results are in full agreement with each other. From the obtained results, it shows that the THD_I is greater than the harmonic limits. Therefore the transformer faces unbalanced load problems. The harmonic cause an increase in neutral line current and unbalanced load on the transformer. Additionally, these PQ problems will cause the power loss of the distribution PS. Moreover, the harmonic will flow into the distribution PS and might interrupt other end-users appliances that are sharing the same feeder connected at PCC.

For solving the mentioned problems, four types of power filters are designed and simulated with the three phase loaded transformers of the QUCEST campus. From the simulation results, we are able to address that the unbalanced load problem is caused by connecting non-linear loads in the system. Among the four power filters, HAPF configuration has the best harmonics compensation ability with the lower values of the DC-link capacitor and DC-bus voltage compared with the APF. Therefore, the HAPF is the most suitable technique to deal with the power quality problems in QUCEST campus. Moreover, it also proves that the proposed designed control system is workable in hybrid system and gives better results compared to shunt APF.

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REFERENCES

[1] M. Ucar and E. Ozdemir, "Control of a 3-Phase 4-Leg Active Power Filter under Non-Ideal Mains Voltage Condition," *Electric Power Systems Research,* vol. 78, pp. 58-73, 2008.

[2] S. Hardie and N. Watson, *"The Effect of New Residential Appliances on Power Quality,"* in Universities Power Engineering Conference (AUPEC), 2010 20th Australasian, 2010, pp. 1-6.

[3] H. Farooq and C. Zhou, "Analyzing the Harmonic Distortion in a Distribution System Caused by the Non-Linear Residential Loads Research output: Contribution to journal› Article," *International Journal,* vol. 2, pp. 46-51, 2013.

[4] O. K. Ignatius, A. K. Saadu, and O. S. Emmanuel, "Analysis of Copper Losses Due to Unbalanced Load in a Transformer (A Case Study of New Idumagbo 2 x 15-MVA, 33/11-kV Injection Substation)," *International Journal of Research and Reviews in Applied Sciences,* vol. 23, p. 46, 2015.

[5] C. Toader, et al., *"Power Quality Impact of Energy-Efficient Electric Domestic Appliances,"* in Applied and Theoretical Electricity (ICATE), 2014 International Conference on, 2014, pp. 1-8.

[6] R. r. Salustiano, E. Neto, and M. Martinez, "The Unbalanced Load Cost on Transformer Losses at a Distribution System," 2013.

[7] V. Wagner, *et al.*, "Effects of Harmonics on Equipment," *Power Delivery, IEEE Transactions on*, vol. 8, pp. 672-680, 1993.

[8] J. Das, "Passive Filters-potentialities and Limitations," *IEEE Transactions on Industry Applications,* vol. 40, pp. 232-241, 2004.

[9] K. Sakthivel, S. K. Das, and K. Kini, *"Importance of Quality AC Power Distribution and Understanding of EMC Standards IEC 61000-3-2, IEC 61000-3-3 and IEC 61000-3-11,"* in Electromagnetic Interference and Compatibility, 2003. INCEMIC 2003. 8th International Conference on, 2003, pp. 423-430.

[10] R. Langella and A. Testa, "IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems," 2014.

[11] A. Y. Abdelaziz, et al., *"Technical Considerations in Harmonic Mitigation Techniques Applied to the Industrial Electrical Power Systems,"* presented at the 22nd International Conference on Electrical Distribution, 2013.

[12] D. M. Soomro, M. Omran, and S. Alswed, "Design of a Shunt Active Caused by Nonlinear Loads Power Filter to Mitigate the Harmonics Caused by Nonlinear Loads," 2015.

[13] S.-I. Ho, C.-S. Lam and M.-C. Wong, *"Comparison among PPF, APF, HAPF and a Combined System of a Shunt HAPF and a Shunt Thyristor Controlled LC,"* in TENCON 2015-2015 IEEE Region 10 Conference, 2015, pp. 1-6.

[14] D. Dobariya and P. Upadhyay, *"Simulation and Comparison between Hybrid Active Power Filter and Shunt Active Power Filter,"* in 2015 International Conference on Electrical, Electronics, Signals, Communication and Optimization (EESCO), 2015.

[15] B. Raghavaiah and M. Agrawal, "STL Guide to Interpretation of Standard IEC: 60076," *Journal International Association on Electricity Generation, Transmission and Distribution,* vol. 28, pp. 51-57, 2015.

[16] A. Njafi, I. Iskender, and N. Genc, *"Evaluating and Derating of Three-Phase Distribution Transformer Under Unbalanced Voltage and Unbalance Load using Finite Element Method,"* in Power Engineering and Optimization Conference (PEOCO), 2014 IEEE 8th International, 2014, pp. 160-165.

[17] D. M. Soomro and M. Almelian, "Optimal Design of a Single Tuned Passive Filter to Mitigate Harmonics in Power Frequency," 2015.

[18] Y.-S. Cho and H.-J. Cha, "Single-tuned Passive Harmonic Filter Design Considering Variances of Tuning and Quality Factor," *Journal of International Council on Electrical Engineering,* vol. 1, pp. 7-13, 2011.

[19] D. Soomro, S. Chong, Z. Memon, and F. Abbasi, *"Investigation and Design of an Active Power Filter for PQ issue at QUCEST Larkana Campus using MATLAB/SIMULINK,"* in Power System Technology (POWERCON), 2016 IEEE International Conference on, 2016, pp. 1-6.

[20] S. H. Hosseini, T. Nouri, and M. Sabahi, *"A Novel Hybrid Active Filter for Power Quality Improvement and Neutral Current Cancellation,"* in Electrical and Electronics Engineering, 2009. ELECO 2009. International Conference on, 2009, pp. I-244-I-248.

[21] P. Salmeron and S. Litran, "Improvement of the Electric Power Quality using Series Active and Shunt Passive Filters," *IEEE transactions on power delivery,* vol. 25, pp. 1058-1067, 2010.

[22] H. Akagi, "Modern Active Filters and Traditional Passive Filters," *Bulletin of the Polish Academy of sciences, Technical sciences,* vol. 54, 2006.

[23] O. Ucak, I. Kocabas, and A. Terciyanli, "Design and Implementation of a Shunt Active Power Filter with Reduced DC Link Voltage," *TUBITAK-space technologies research institute, power electronics group METU campus, TR,* vol. 6531, 2008.